GEOLOGY OF THE SAN ANDREAS 15-MINUTE QUADRANGLE, CALAVERAS COUNTY, CALIFORNIA

BULLETIN 195

California Division of Mines and Geology
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By Lorin D. Clark
U.S. Geological Survey
Menlo Park, California

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ABSTRACT

The San Andreas quadrangle is underlain chiefly by folded and metamorphosed sedimentary and volcanic rocks of late Paleozoic and Mesozoic age. These are intruded by ultramafic and felsic plutonic rocks. Paleozoic rocks are chiefly altered chert and carbonaceous shale but include some carbonate and volcanic rocks. Upper Jurassic formations consist of pyroclastic rocks, silty slate, graywacke, and conglomerate. Chemical analyses of eleven volcanic rocks suggest that their original composition was altered by post-eruptive processes. The metamorphic rocks are cut by two steeply dipping major fault zones, along one of which Paleozoic strata are juxtaposed against Upper Jurassic strata throughout the length of the quadrangle. Very incomplete production records show that more than $54 million in gold was recovered from lode and placer deposits in the quadrangle. The chief mineral industry in 1967 and for the two previous decades was the manufacture of cement from locally mined limestone. Silver was recovered from some gold ores, and chromite was produced prior to 1920.

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By LORIN D. CLARK

INTRODUCTION

The San Andreas quadrangle is on the lower western slope of the Sierra Nevada (fig. 1) and is underlain chiefly by Paleozoic and Jurassic metamorphic rocks but in part by Jurassic plutonic rocks. The Mother Lode gold belt extends across the quadrangle from the southeast to the northwest corner, and the present towns of the region were established as lode and placer mining centers during the gold rush that began in 1848. Since World War II, however, gold production has been modest, and the principal mineral industry of the quadrangle has been the operation of the plant and quarries of the Calaveras Cement Company near San Andreas.

Physiographically, the San Andreas quadrangle is typical of much of the western Sierra Nevada. It is divisible into two contrasting areas. Southwest of the Mother Lode, the most prominent features are northwest-trending ridges underlain by massive metavolcanic rocks and valleys underlain by slate or schistose metavolcanic rocks. The area northeast of the Mother Lode is a gently rolling and deeply weathered upland surface underlain largely by deformed and metamorphosed sedimentary rocks. This surface is interrupted southeast of Calaveritas by a broad east-trending lowland that coincides approximately with the area underlain by schistose metavolcanic rocks of the Calaveras Formation.

The rolling upland surface and the northwest-trending ridges that rise above the general level of this surface were shaped largely during Late Cretaceous and early Eocene time, when the Sierra Nevada stood much lower than at present. Steep-walled canyons dissect the upland surface in the northeast part of the quadrangle. These canyons and the canyon of the Stanislaus River in the extreme southeast corner of the quadrangle are younger features that result from uplift of the Sierra Nevada and more rapid erosion during later Tertiary and, probably, Quaternary time.

The main purpose of this report is to discuss previously undescribed geological features of the San Andreas quadrangle. Geologic studies of the area began shortly before 1890 and were continued intermittently to the present time, but until 1946 the geologic folio reports of the Jackson quadrangle, prepared by H. W. Turner (1894), and the Mother Lode belt, prepared by F. L. Ransome (1900), were the only geologic maps in the area of the San Andreas quadrangle. To develop a better understanding of the structure, stratigraphy, and origin of rocks along the Mother Lode, mapping of the San Andreas quadrangle (pl. 1) was begun in 1946 by the U.S. Geological Survey in cooperation with the California Department of Natural Resources, Division of Mines (now California Department of Conservation, Division of Mines and Geology). The first results of that program were geologic maps of the Calaveritas 7½-minute quadrangle (Clark, 1954) and the Angels Camp and Sonora 7½-minute quadrangles (Eric and others, 1955). The location of these quadrangles is shown on figure 1. An aeromagnetic map which includes the southern two-thirds of the quadrangle (Henderson and others, 1966) shows that positive magnetic values are associated with serpentine and negative anomalies are associated with schistose metavolcanic rocks. Anomalies generally parallel geologic structure within the quadrangle. Field work in the western half of the San Andreas quadrangle and field checking in the eastern half were substantially complete in 1952, but publication of the map was delayed until stratigraphic and structural studies of a larger region (Clark, 1964) could enhance understanding of the quadrangle.

The reports cited above provide descriptions of the chief structural and stratigraphic features of the San Andreas quadrangle, and the mineral deposits have been described by W. B. Clark and P. A. Lydon (1962). Pertinent findings of published investigations are summarized in this report.

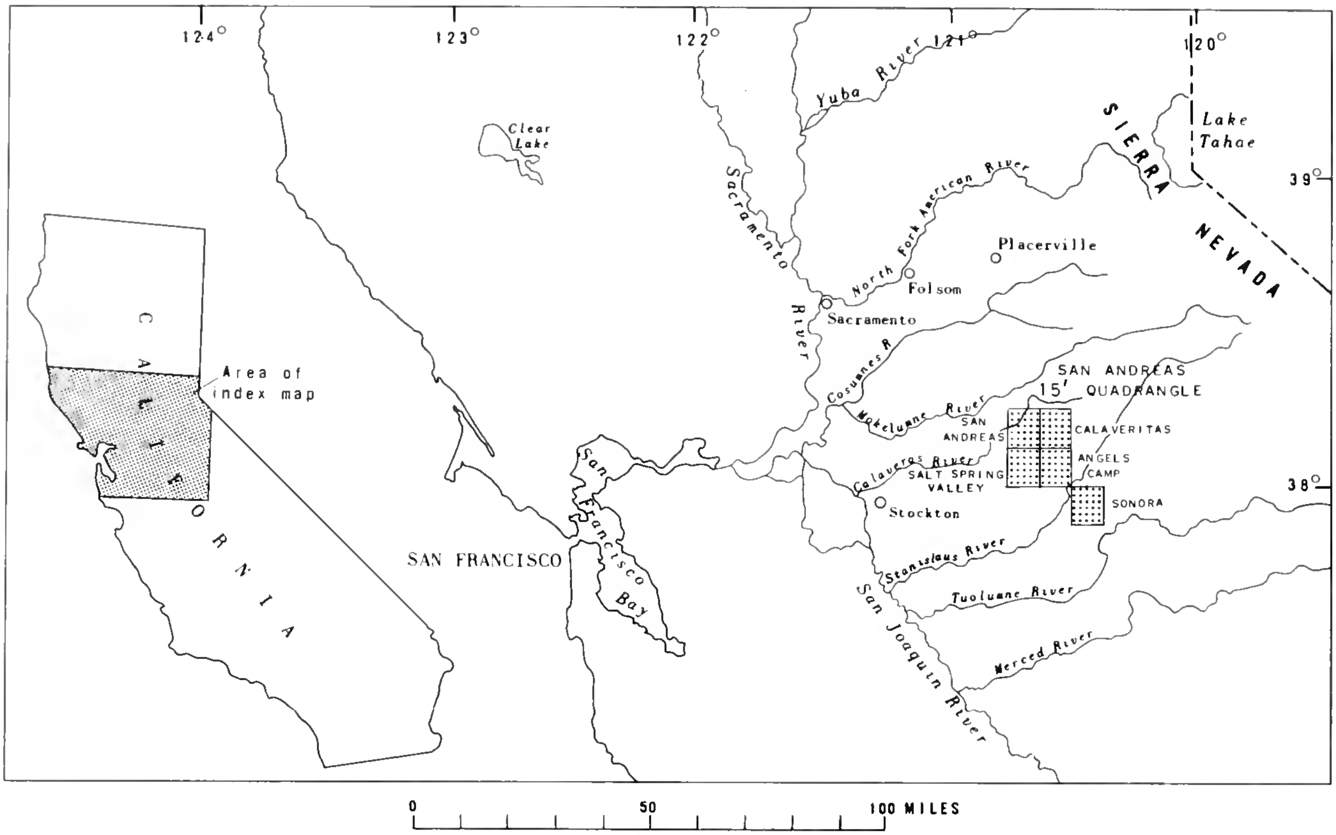


Figure 1. Index Map. The locations of the San Andreas 15-minute quadrangle and component 7½-minute quadrangles are shown.

This report benefits greatly from discussions during the course of the mapping with J. H. Eric, A. A. Stromquist, C. M. Swinney, and D. B. Tatlock, and as a result of revisions suggested by R. G. Yates, P. B. King, and Arthur Grantz, U.S. Geological Survey.

DEFINITIONS OF CERTAIN TERMS

Although all the pre-Tertiary sedimentary and volcanic rocks in the region are metamorphosed, original structures and textures are commonly well preserved, and the emphasis of this study is on their structure and stratigraphy rather than their metamorphism. For this reason, as well as to avoid tiresome repetition of the prefix "meta", the rocks are generally designated by such names as chert and tuff rather than metachert and metatuff. Lack of consistency will be apparent, however, for originally argillaceous rocks are referred to as slate, phyllite, and schist, and volcanic rocks in which original textures are destroyed by shearing are termed green schist.

The term "graywacke" designates poorly sorted sandstone with a matrix of silt-size and originally clay-size material (Pettijohn, 1954; 1957, p. 290–292). Sand grains are mostly chert or other lithic fragments, but various amounts are mineral grains, most commonly quartz. Rocks of appropriate grain-size class in which the sand-size fraction consists entirely of volcanic rock and mineral detritus are called tuff.

A problem in nomenclature is posed by bedded clastic rocks within the grain-size range of sandstone that contain fragments of volcanic rocks and minerals as well as rock and mineral fragments derived from older metamorphic rocks. If the volcanic material in such rocks is of first-cycle pyroclastic origin, the rock is appropriately termed tuffaceous sandstone, but if the volcanic material was derived by weathering and erosion from an older volcanic terrain, the word "tuffaceous" is not suitable. The distinction between first- and second-cycle volcanic fragments has not been made in the metamorphosed strata of the western Sierra Nevada. For this reason, fragmental rocks of appropriate grain-size class range that contain volcanic rock detritus but include even a very small proportion of epiclastic grains derived from sedimentary, metamorphic, and intrusive rocks are included arbitrarily under the term graywacke. No fundamentally important aspect of the interpretation of geologic history of the region is masked by this usage, inasmuch as sequences of definite first-cycle volcanic material alternate with sequences of definite epiclastic material on both the regional scale and the scale of a single formation.

In the absence of a purely descriptive term, the name "chert" is applied to thin-bedded, microcrystalline, granoblastic rocks composed of quartz. These rocks lack clastic textures and contain sparse structures commonly thought to be radiolarians (for example, Taliaferro, 1943, p. 289). In this area, such rocks have been referred to by most previous geologists as either phthanite or quartzite. The term "phthanite" has fallen into disuse in this country, and, although quartzite is often used as a descriptive term, it is more properly applicable to a rock formed from quartz sand. Most of the chert is micaceous, and rock containing so much mica that it can be scratched with a hammer point is here referred to as quartzose slate.

"Schistosity" designates a planar structure formed by the parallel arrangement of tabular mineral grains and clastic fragments in rocks sufficiently coarse grained to be termed schist. In strongly sheared schist, slip surfaces generally parallel to grains and fragments accentuate the cleavage. "Slip cleavage" consists of closely spaced crinkles and microfaults (White, 1949) cutting earlier schistosity and cleavage. Previously formed mica flakes are commonly bent to a direction parallel to the microfaults.

STRATIGRAPHY

Rocks of Paleozoic age in the San Andreas quadrangle consist of the Calaveras Formation, of late Paleozoic age, and rocks that resemble the Shoo Fly Formation of Silurian(?) age, exposed north of Placerville (fig. 1). Sedimentary and volcanic rocks of the Calaveras Formation underlie the northeastern part of the quadrangle. Slump blocks derived from the Calaveras Formation, some large enough to be mapped separately, broke loose during Late Jurassic time and were incorporated in the sediments of the Mariposa Formation. They are particularly abundant in the northwestern part of the quadrangle (pl. 1). Paleozoic sedimentary rocks of uncertain stratigraphic position (map symbol Pzu), but probably equivalent to the Shoo Fly Formation, are exposed near Kentucky House.

Layered rocks of Late Jurassic age underlie most of the southwestern half of the quadrangle. They are a eugeosynclinal accumulation of intertonguing sedimentary and volcanic rocks having a total exposed thickness in excess of 15,000 feet. The volcanic rocks are chiefly of pyroclastic origin but include some lava. The sedimentary rocks are mostly silty slate, but graywacke and lenses of conglomerate are locally abundant; chert is sparse. Graded beds indicative of turbidity-current deposition and coarse, poorly size-sorted layers resulting from submarine mudflows are common in both volcanic and sedimentary formations.

The chief reference for the chronologic sequence of map units is the left-hand column of the geologic map explanation (see pl. 1), which is continued stratigraphically downward at the right border of the map sheet. In the three columns to the right of the reference column, units are arranged in their most probable position relative to the reference column. An exception is that the Salt Spring Slate, which has yielded few fossils, appears in the reference column instead of the better-dated Mariposa Formation, in order to preserve uninterrupted the concordant sequence of formations in the southeast part of the quadrangle.

Paleozoic Rocks

SEDIMENTARY ROCKS OF UNCERTAIN STRATIGRAPHIC POSITION

Paleozoic rocks of uncertain stratigraphic position (Pzu) constitute two bodies of sedimentary rocks separated by serpentine in the western part of the Melones fault zone south of San Andreas. The northern body is poorly exposed except in limestone quarries near Kentucky House, but, according to Stromquist (oral commun., 1952), weathered quartz-bearing sandstones occur in some places. The body south of the serpentine is better exposed, especially near the confluence of Steele and San Domingo Creeks. It consists of interbedded quartzite, arkose, slate, thin-bedded chert, and graywacke in which nearly all the sand-size grains are roundish quartz. Most of these rocks are schistose, and, in places, they are folded. Most contacts of this unit with surrounding rocks are faults, but along San Domingo Creek, the contact with Jurassic conglomerate is apparently an unconformity, for the conglomerate contains pebbles of the same compositions as the Paleozoic rocks exposed at the mouth of Steele Creek.

Although these sedimentary bodies were previously included arbitrarily with the Calaveras Formation (Clark, 1964, pls. 1–2), further work suggests that they resemble the Shoo Fly Formation of Silurian(?) age. Interbedded arkose, quartzose graywacke, and quartzite constitute an unusual assemblage of rock types but one that is characteristic of the Shoo Fly Formation, which underlies a large area in the northern Sierra Nevada (Clark and others, 1962, fig. 6.2) and bounds the east side of the Melones fault zone about 10 miles north of Placerville (fig. 1).

CALAVERAS FORMATION

The Calaveras Formation was divided by Clark (1964, p. 8) into four lithologic members, but in the San Andreas quadrangle only three stratigraphic units are shown. Here the formation consists of sedimentary rocks that constitute an undifferentiated chert and argillaceous unit (Pzc), carbonate rocks (Pzcl), and a volcanic unit (Pzcv). Graded beds about three miles east of Calaveritas show that the volcanic unit there underlies the sedimentary rocks, but possibly volcanic rocks at more than one stratigraphic level have been included in this unit elsewhere in the quadrangle. The Calaveras Formation is in fault contact with the Jurassic strata and with the green schist of the Melones fault zone. Although shearing of the formation has obliterated bedding nearly everywhere and estimates of thickness are very crude, the great size of the area in the western Sierra Nevada underlain by the Calaveras Formation suggests that its thickness is measurable in thousands of feet. The most readily accessible good exposures of sedimentary rocks other than limestone are along Murray Creek on a road leading east from San Andreas and in the Calaveritas Hill Consolidated hydraulic mine pit. Volcanic rocks of the formation are also exposed in the pit and along the road to the east. Foraminifera and corals found outside the quadrangle indicate that some carbonate rocks of the Calaveras Formation are of Permian age, but parts of the formation may be older.

The dominant sedimentary rocks of the Calaveras Formation are microcrystalline chert thinly interbedded with dark-gray phyllite and rocks gradational in composition between the chert and phyllite. Possibly, fine-grained orthoquartzite or quartz siltstone occurs in the quadrangle, for minor amounts of such rocks are interbedded with the phyllite and chert assemblage elsewhere in the western Sierra Nevada. Carbonate rocks in the undifferentiated chert and argillaceous members of the Calaveras Formation northeast of the Melones fault zone range from coarsely crystalline or medium-grained limestone to fine-grained recrystallized dolomite or dolomitic limestone. Original textures have been destroyed in most of these rocks. On the other hand, in carbonate blocks detached from the main body of the Calaveras Formation and emplaced by slumping into the Mariposa Formation, calcarenites composed largely of crinoid fragments or, more rarely, of foraminifera are recognizable. Regional distribution suggests that carbonate rocks of the Calaveras Formation were deposited as lenses, rather than as broad sheets of regional extent.

The volcanic member of the Calaveras Formation in the San Andreas quadrangle is mostly green schist whose mineralogy suggests a volcanic origin. In places, bedding can be observed, and in secs. 32 and 33, T. 4 N., R. 13 E., graded argillaceous or silty layers are interbedded with the volcanic rocks.

Jurassic Rocks

The Jurassic sequence is divided into the Gopher Ridge Volcanics, Salt Spring Slate, Copper Hill Volcanics, Mariposa Formation, and unnamed units. This subdivision separates thick volcanic units from thick sedimentary units but fails to portray adequately the complexity of the stratigraphic section (see Clark, 1964, pl. 9). The lenticular form of the mapped units is suggested by the outcrop pattern of the Brower Creek Volcanic Member of the Mariposa Formation at Bear Mountain and to the northwest and by tongues or lenses of volcanic rocks in the Salt Spring Slate, but outcrops do not permit consistent delineation of the smaller lithologic units that are classed together as a formation. Fossils in most of the formations indicate their Jurassic age (Imlay, 1961) but are too unevenly distributed to demonstrate a detailed time-stratigraphic sequence.

These properties of the Jurassic rocks, as well as lateral facies changes and repetition of similar lithologies in different parts of the geologic section, preclude accurate correlation between structural blocks that are separated by faults or major fault zones (cross section, pl. 1). Accordingly, formation names for Jurassic rocks are in this report restricted along strike to rocks within belts of exposure that are continuous with type areas, and across the strike to strata demonstrably repeated by folding (see Clark, 1964, p. 15–16). Consistent with this procedure, the Salt Spring Slate, which is lithologically similar but not identical to the Mariposa Formation, is described as a separate formation, although sparse paleontologic evidence in the Salt Spring (Imlay, 1961, p. 13–19, especially locality 8, table 3; Imlay, cited by Clark, 1964, p. 29) suggests that its lower part is about the same age as the lower part of the Mariposa Formation.

Some unnamed bodies of volcanic sedimentary rocks that are probably of Jurassic age cannot be confidently assigned to recognized formations because they lack fossils and their contacts are concealed or are faults. These rocks are distinguished on the map (pl. 1) as volcanic and sedimentary rocks, respectively, of uncertain stratigraphic position and will be discussed separately. Lithologically, most rocks in these units are similar to the known Jurassic formations, and correlations are suggested for some units, but solution of remaining stratigraphic and structural problems is best served by clear identification of uncertainties in correlation.

VOLCANIC ROCKS

The various Jurassic stratigraphic units in the San Andreas quadrangle that are composed of volcanic rocks are very similar to one another; although they vary in composition from basalt to quartz keratophyre, rocks of intermediate compositions predominate. The volcanic formations are mostly bedded pyroclastic rocks ranging from very fine tuff to very coarse volcanic breccia, but some massive lava occurs, and pillow lava is exposed along Bear Creek near the west side of a tongue of the Brower Creek Volcanic Member of the Mariposa Formation.

Tuffs range in texture from very fine grained rocks that resemble slate when weathered to lapilli tuff and coarse-grained tuff. Volcanic breccias also range widely in coarseness and sorting; the largest blocks, as much as two feet long, are in the Brower Creek Volcanic Member of the Mariposa Formation along Steele Creek south of Joaquin Peak. In some volcanic breccias, all the rock fragments are alike, but in others the fragments are diverse in texture and mineralogy (fig. 2). Volcanic bombs were seen only in roadcuts half a mile southwest of Carmen Peak where they are in a matrix of sheared tuff. Marine fossils and sedimentary structures (Clark, 1964, p. 39–40) show that most, and possibly all, of the pyroclastic rocks were deposited in a submarine environment. Presumably, the vents from which the volcanic rocks were erupted were offshore, but the relative amounts of submarine and subaerial eruptives are unknown, for nearly everywhere evidence of the rate of chilling of volcanic rock fragments was destroyed by metamorphism. Massive lava is not necessarily subaerial, for elsewhere in the western Sierra Nevada, Jurassic pillow

Figure 2. Brower Creek Volcanic Member of the Mariposa Formation. Poor size sorting and diverse textures characterize the component rock fragments. Penny shows scale. The roadcut, in SE¼ sec. 35, T. 3 N., R. 12 E., is the site from which Sample 156-552, table 1, was taken.

lavas grade upward into massive lava through zones in which distinct selvages around individual pillows change into obscure disconnected lines.

Depositional textures of the tuff, readily apparent in fresh exposures, are obscured under the microscope by a fine-grained matte of metamorphic minerals formed by the recrystallization of abundant rock fragments. Determination of minerals in thin section is difficult because of fine grain size, but uralitic amphibole, albite, chlorite, quartz, and minerals of the epidote and zoisite or clinozoisite groups are widespread. Primary pyroxene crystals remain in many of the nonschistose pyroclastic rocks. Textural evidence as to whether the rock fragments were originally glassy or crystalline has been destroyed by metamorphism.

The chemical composition of many of the eruptive rocks has been modified by metamorphism, depositional sorting, and possibly by submarine weathering and diagenesis. Metamorphic redistribution of elements is indicated by calcite and chlorite vesicle fillings, and by veins of epidote, quartz, and calcite. Depositional sorting is shown by graded tuff beds in which crystals are concentrated in the lower part of a bed and lithic fragments in a higher part. Submarine weathering of the clay and silt-size grains that compose the fine-grained tuff is possible but not proved.

In view of field and laboratory evidence for post-eruptive compositional changes in the volcanic rocks, the extent to which original magma suites can be identified is not clear. A comprehensive chemical study of

Table 1. Rapid Chemical Analyses of Metavolcanic Rocks

Lab. No.	156–552	156–553	156–554	156–555	156–556	156–557	156–558	156–559	156–560	156–561	156–562
SiO_2	55.6	67.3	69.2	76.5	49.2	45.2	47.0	47.4	51.4	54.9	53.0
Al_2O_3	16.4	13.0	14.1	11.7	14.6	16.2	14.1	14.9	14.9	16.1	17.5
Fe_2O_3	.7	1.5	1.3	.3	1.0	1.6	1.5	2.1	2.1	.4	.2
FeO	6.4	4.6	3.4	2.3	8.0	8.0	5.8	10.4	7.4	7.8	5.8
MgO	3.5	1.9	1.5	.68	8.5	7.7	4.5	6.6	5.1	5.5	3.5
CaO	7.7	6.3	3.7	.79	8.9	9.0	13.2	7.9	9.6	5.0	5.5
Na_2O	2.9	.95	4.8	5.6	3.6	2.8	4.6	3.9	4.1	5.9	6.0
K_2O	2.0	.81	.13	.32	.87	1.6	.24	.30	.06	.48	.52
H_2O	3.3	2.4	1.8	1.2	3.8	4.7	2.9	4.2	3.6	3.4	2.9
TiO_2	.87	.84	.57	.37	1.1	1.2	1.1	1.8	1.8	.66	.68
P_2O_5	.23	.19	.09	.05	.25	.15	.13	.19	.17	.05	.08
MnO	.16	.16	.12	.13	.16	.19	.21	.23	.20	.19	.16
CO_2	.13	<.05	<.05	.08	.20	1.8	5.5	.22	.07	<.05	<.05
FeS_2*	.19	<.10	<.10	<.10	<.10	<.10	<.10	<.10	<.10	<.10	4.3
Sum	100	100	101	100	100	100	101	100	100	100	100

* Total sulfur calculated to FeS_2.
Analyses by P. L. D. Elmore, S. D. Botts, I. H. Barlow and G. Chloe, U.S. Geological Survey.

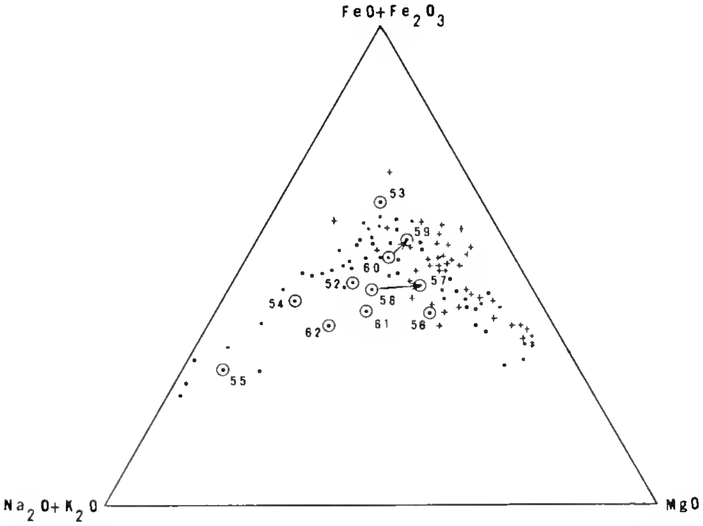


Figure 3. AFM Diagram Comparing Composition of Western Sierra Nevada Metavolcanic Rocks with Hawaiian Basalts. Circled symbols indicate Sierra rocks; dots, alkali series; crosses, tholeiite series. Arrows point from core to rim of single pillow. Samples are identified by the last two digits of laboratory number.

these rocks is beyond the scope of this investigation but 11 samples of diverse western Sierra Nevada volcanic rocks are presented (table 1) to illustrate problems involved in determining major suites. CIPW norms of the analyzed rocks are given in table 2. Plotted on an AFM diagram (fig. 3) and compared with Hawaiian volcanic rocks (Kuno and others, 1957; Coleman and Lee, 1963, fig. 19A), the analyses suggest affinities with the alkali series, but the possibility that some belong to the tholeiite series is not excluded. On a plot of total alkali versus silica (fig. 4), the western Sierra Nevada metavolcanic rocks, except the highly silicic ones, lie near the alkali series-tholeiite series boundary. The variation diagram (fig. 5) shows, in its pronounced reversals of slope, considerable divergence from comparable plots of a series of fresh volcanic rocks.

Differences in composition between cores and rims of two pillows that appear in the field to be parts of the same flow (sample Nos. 156-557, 156-558, 156-559, 156-560, table 1) were first noticed by Donald B. Tatlock (oral commun., 1962), who found by means of stained slabs that K-feldspar occurred in the margins of the pillows but not in the centers. These differences between cores and rims of individual pillows, as well as those between the two pillows, are shown in the diagrams referred to above, and are emphasized by the Rittman classification (1952) based on chemical analyses; in one pillow (samples 156-557 and 156-558) the rim is olivine trachybasalt, and the center is andesite; in the other (samples 156-559 and 156-560), the rim is pigeonite-labradorite andesite or olivine-andesine basalt, and the center is andesine basalt. According to Moore's (1966, p. 170) study of unmetamorphosed Hawaiian submarine lava pillows, such chemical differences between cores and rims of pillows can be attributed to replacement of basalt glass by palagonite, apparently through exchange with sea water.

SEDIMENTARY ROCKS

Upper Jurassic sedimentary rocks in the San Andreas quadrangle are largely slate and graywacke

Table 2. CIPW Norms of Metavolcanic Rocks

Lab. No.	156–552	156–553	156–554	156–555	156–556	156–557	156–558	156–559	156–560	156–561	156–562
q	7.99	40.36	29.13	38.74	0.00	0.00	0.00	0.00	0.81	0.00	0.00
c	.00	.00	.00	1.01	.00	.00	.00	.00	.00	.00	.00
or	11.82	4.79	.77	1.89	5.14	9.45	1.42	1.77	.35	2.84	3.07
ab	24.53	8.03	40.59	47.36	30.45	23.68	38.90	32.98	34.67	49.90	50.74
an	25.83	28.82	16.55	3.09	21.11	26.91	17.12	22.27	22.08	16.04	19.29
wo	4.19	.50	.51	.00	8.40	2.24	5.32	5.96	.01	3.52	3.12
en	8.71	4.73	3.73	1.69	5.41	3.68	8.73	5.14	12.70	5.59	5.75
fs	10.03	6.12	4.45	3.61	3.16	2.25	6.22	4.63	9.25	5.41	3.25
fo	.00	.00	.00	.00	11.03	10.86	1.73	7.91	.00	5.68	2.07
fa	.00	.00	.00	.00	7.09	7.33	1.36	7.86	.00	6.05	1.29
mt	1.01	2.17	1.88	.43	1.45	2.32	2.17	3.04	3.04	.58	.29
il	1.65	1.60	1.08	.70	2.09	2.28	2.09	3.42	3.42	1.25	1.29
ap	.54	.45	.21	.12	.59	.35	.31	.45	.40	.12	.19
pr	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	4.30
cc	.30	.00	.00	.18	.45	4.09	12.51	.50	.16	.00	.00
Total	96.60	97.57	98.90	98.84	96.37	95.44	97.88	95.93	96.93	96.98	94.65
Sal	70.16	82.00	87.04	92.09	56.70	60.04	57.44	57.02	57.91	68.78	73.10
Fem	26.44	15.57	11.86	6.75	39.67	35.40	40.44	38.91	39.02	28.20	21.55

Lab. No.	**Location and Description of Samples**
156-552	Roadcut, west side California State Highway 4, SE¼ sec. 35, T. 3 N., R. 12 E.; San Andreas 15′ quad., Calaveras County, Calif. Volcanic breccia from Brower Creek Volcanic Member of Mariposa Formation. Fragments in the breccia are of several different textures. Poorly sorted; no internal layering in breccia bed. Chip sample across 15-foot width of exposure.
553	Roadcut, south side of Rock Creek gorge, NE¼SW¼ sec. 16, T. 2 N., R. 11 E., Valley Springs 15′ quad., Calaveras County, Calif. Very fine-grained, thin-bedded felsite tuff. Chip sample across 8-foot stratigraphic thickness.
554	Roadcut, south side of Rock Creek gorge, NE¼SW¼ sec. 16, T. 2 N., R. 11 E., Valley Springs 15′ quad., Calaveras County, Calif. Coarse felsite tuff. Poorly sorted. Fragments are of diverse texture and structure. Chip sample across 5 feet stratigraphically.
555	Roadcut, south side of Rock Creek gorge, SW¼ sec. 16, T. 2 N., R. 11 E.; Valley Springs 15′ quad., Calaveras County, Calif. Massive porphyritic felsite from lava or welded ash. Locally contains felsite inclusions up to three-sixteenths of an inch long. Chip sample across 50 feet in a direction normal to strike.
556	Roadcut, west side of California State Highway 49, 100 to 150 feet south of south end of Huse Bridge across the Cosumnes River, NW¼ sec. 14, T. 8 N., R. 11 E., Amador County, Calif. Top of Logtown Bridge Formation, about 20 feet west of contact with Mariposa Formation. Coarse volcanic breccia with pyroxene phenocrysts. Chip sample across stratigraphic thickness of 8 feet.
557	Roadcut, west side of California State Highway 20, about 100 feet south of south end of Yuba River bridge, NW¼ sec. 29, T. 16 N., R. 6 E., Smartville 7½′ quad., Yuba County, Calif. Outer 1 inch of mafic lava pillow about 15 inches long and 9 inches in diameter. Weathered chlorite rim trimmed off.
558	Center 2 inches of the same pillow as Sample 557.
559	Same locality as Sample 557. Outer 1½ inches (except weathered chlorite rim) of mafic lava pillow about 26 inches in diameter.
560	Center 4 inches of same pillow as Sample 559.
156-561	Roadcut, east side of California State Highway 4, about 500 feet south of the south boundary of the San Andreas 15′ quad., Calaveras County, Calif. Central 0.7 inch of medium-grained graded tuff bed that is 1 inch thick.
562	Same locality as Sample 561. Very fine-grained tuff bed 0.4 inch thick. Center of this sample is 1.5 inches stratigraphically above center of LC-59–96A. The two beds sampled are separated by fine-grained tuff.

but include some lenticular polymictic conglomerate (containing fragments of diverse rocks), and the Mariposa Formation contains some chert and quartzose slate. Although the slates have good cleavage, study of thin sections reveals that they were metamorphosed from siltstone rather than shale. The graywacke beds are commonly graded.

Conglomerate is particularly coarse and abundant in the Mariposa Formation northwest of Steele Creek and in Jurassic rocks of uncertain stratigraphic position near Cherokee Creek and northwest of San Andreas. Conglomerates in the Salt Spring Slate are sparser and finer grained. Some conglomerate layers are apparently current-deposited: they are internally

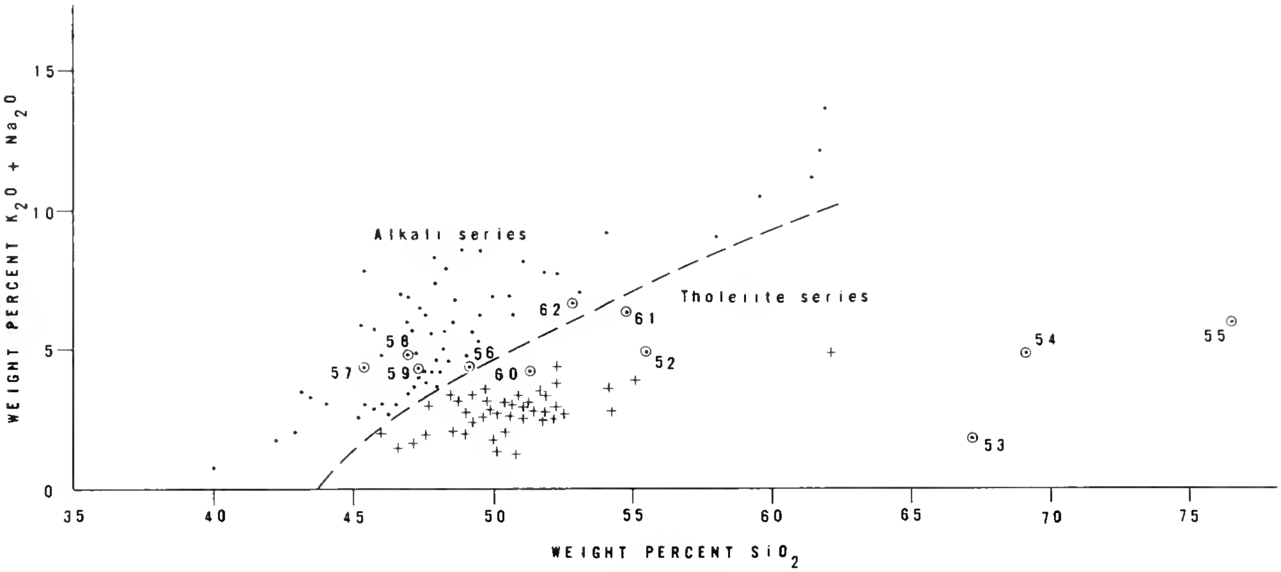
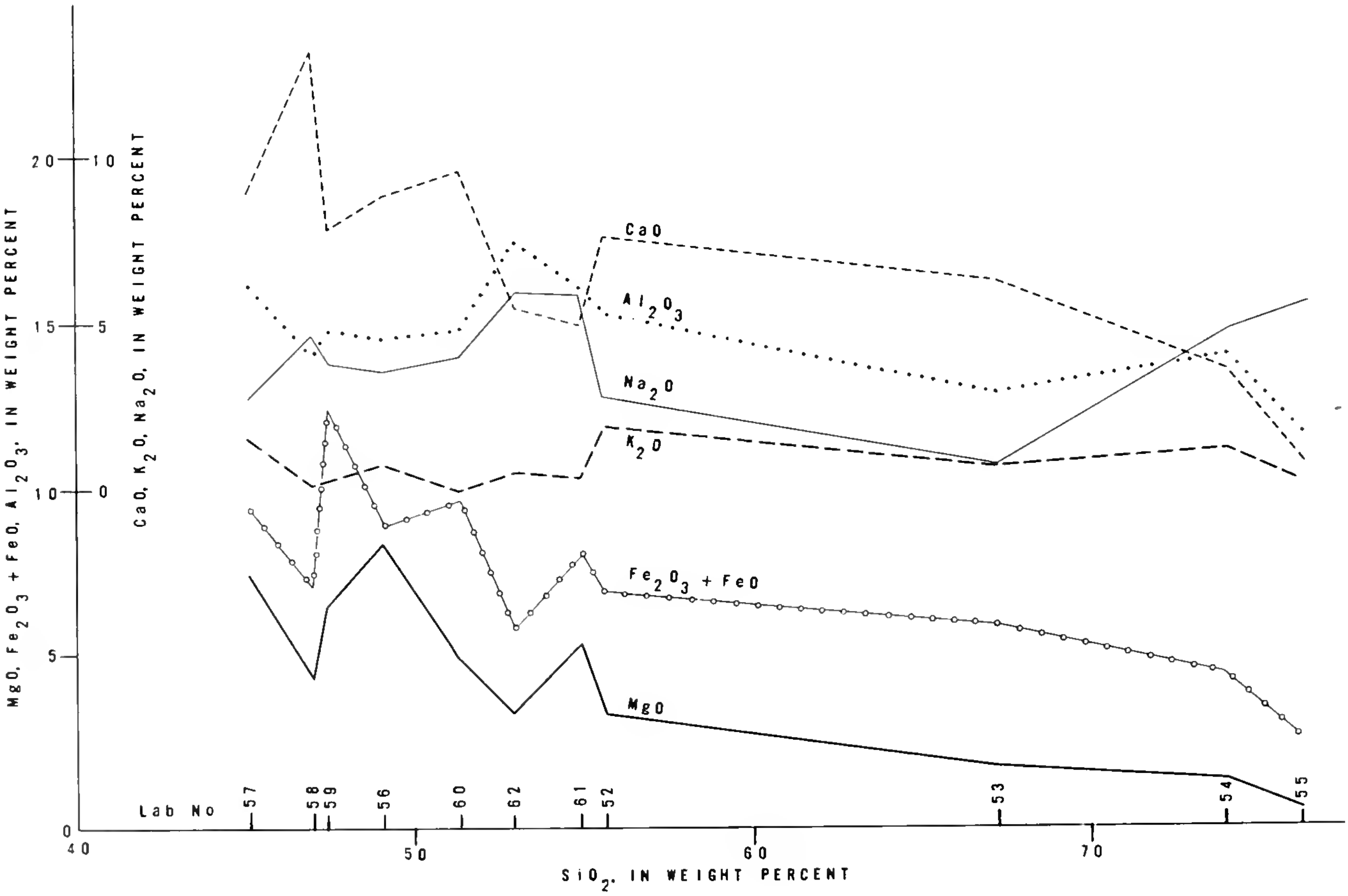


Figure 4. Alkali versus Silica, Volcanic and Metavolcanic Rocks. Hawaiian basalts: dots, alkali rock series; crosses, tholeiite series (redrawn from Kuno and others, 1957). Western Sierra Nevada metavolcanic rocks: circled dots.

Figure 5. Variation Diagram for Metavolcanic Rocks.



bedded and the degree of sorting is comparable with that of the much younger alluvial gravels. Other conglomerate layers, best exposed in the SW¼ sec. 1, T. 3 N., R. 11 E., are apparently mudflow deposits: they lack internal bedding, and the sorting is very poor, as in the pebbly mudstones described by Crowell (1957). The conglomerates contain pebbles of volcanic rocks similar to those of the Jurassic formations in the quadrangle, and the slate resembles that of the Mariposa Formation; possibly the volcanic rock and slate fragments were derived from uplifted marginal parts of the trough in which the Upper Jurassic sediments accumulated. The dark-gray chert fragments may have been derived from the Calaveras Formation, as were some pebbles and blocks mentioned in the description of the Mariposa Formation. Pebbles of quartzite, arkose, quartz-rich graywacke, calcareous orthoquartzite, and light-colored chert were probably derived from the Shoo Fly Formation.

Compositions of sand grains in graywacke of the Upper Jurassic formations are consistent with the pebble composition in the conglomerates; the sand grains are composed of volcanic rocks and minerals, strained and unstrained quartz, chert, feldspar, and fragments of metamorphic rocks. Graywackes composed chiefly of volcanic rocks and minerals are difficult to distinguish megascopically from tuff, but this seldom is a problem in mapping, as the graywacke is interbedded with slate, whereas tuff is normally associated with readily recognizable coarser pyroclastic rocks in layered units commonly several tens of feet thick.

Blocks of carbonate rock as much as 100 feet long occur in polymictic conglomerates of the Mariposa Formation and in Jurassic rocks of uncertain stratigraphic position along Cherokee Creek. Some blocks in the Mariposa Formation contain fossils of Permian age, and one block is of Triassic or, possibly, Permian age (J. E. Smedley, cited by Clark, 1964, p. 14–15). No fossils were found in the carbonate blocks on the north side of Cherokee Creek, but these were probably derived from Paleozoic recrystallized limestone of uncertain stratigraphic position (unit Pzu) comparable to those near Kentucky House. Breccia structure is characteristic of some carbonate blocks, but whether this is of sedimentary or deformational origin is unclear. No evidence of reef structures was found within the blocks, and their nearly equidimensional outlines, together with their association with poorly sorted petromict conglomerate, suggest that the blocks were emplaced by slumping. Poorly exposed, deformed thin-bedded chert exposed at the south boundary of sec. 20, T. 3 N., R. 12 E., is also believed to be a slumped block derived from the Calaveras Formation. King (1937, p. 66–68, 89–92) has described similar large blocks emplaced by slumping into the area of deposition of sediments that now enclose them.

DESCRIPTIONS OF FORMATIONS

Gopher Ridge Volcanics

The Gopher Ridge Volcanics, of Jurassic (probable Late Jurassic) age, conformably underlies the Salt Spring Slate. The formation crops out in a small area in the southwestern corner of the quadrangle but is poorly exposed. Good exposures in the Valley Springs quadrangle to the west occur along Rock Creek, which flows westward from Salt Spring Valley Reservoir. The Gopher Ridge Volcanics contain more silicic rock than do other Jurassic volcanic formations in the region; some of the silicic rocks are probably penecontemporaneous hypabyssal intrusives (Clark, 1964, p. 28–29), but silicic rocks in the section along Rock Creek include very fine tuff, medium-grained tuff, and fine-grained volcanic breccia, as well as a massive unit that may be a lava or welded ash (sample 156-555, table 1).

Salt Spring Slate

The Salt Spring Slate, of Late Jurassic (late Oxfordian to early Kimmeridgian) age, intertongues with the overlying Copper Hill Volcanics in the southwestern part of the quadrangle. Bodies of volcanic rocks are tentatively mapped as lenses within the Salt Spring Slate, but possibly these "lenses" are cross sections of tongues extending in the dip direction from the Copper Hill Volcanics. Width of outcrop and measured dips suggest that the Salt Spring has a total thickness of 10,000 feet, but outcrops are poor, and part of the section may be repeated by undiscovered folds.

Mariposa Formation

Interbedded pyroclastic and sedimentary rocks of the Mariposa Formation form a fault-bounded syncline near the center of the quadrangle. Fossils of Late Jurassic (late Oxfordian to early Kimmeridgian) age have been collected from the lower and middle parts of the Mariposa Formation, but the upper part of the formation has not been dated. Volcanic breccia and tuff exposed chiefly on the west limb of the syncline and to a lesser extent on the east limb form the Brower Creek Volcanic Member of the Mariposa Formation. Tuff is interbedded with slate and graywacke along Angels Creek (see Eric and others, 1955, pl. 1), but away from the creek, exposures are too poor to differentiate tuff from slate consistently. Thinly interbedded dark-gray slate, siliceous slate, and chert occur in the Mariposa Formation near Deer Peak southwestward to Steele Creek. The exposed thickness of the Mariposa Formation in the quadrangle is probably more than 8,000 feet, but neither the base nor the top of the formation is known to be exposed. The most readily accessible good exposures of the Mariposa Formation are along the railroad grade on the north side of the Calaveras River, but the formation is also well-exposed along Steele Creek and Angels Creek.

Rocks here included with the Brower Creek Volcanic Member of the Mariposa Formation were assigned to the Logtown Ridge Formation by Eric and others (1955, pl. 1), who interpreted the map pattern in the vicinity of Fowler Lookout and Brower Creek to be the result of folding. More detailed mapping has revealed graded bedding in two tongues of volcanic rock near Elkhorn Station. The mapping shows that top directions of both tongues are eastward and that the map pattern on the steeply dipping southwest limb of the syncline occupied by the Mariposa Formation reflects, not folding, but intertonguing of the volcanic and sedimentary rocks. The thick section of volcanic rocks near Brower Creek and Fowler Lookout apparently accumulated very close to the vent from which the rocks of the Brower Creek Volcanic Member were erupted, for the rocks here are very coarse heterogeneous volcanic breccia. The coarse breccia is bounded on the northeast, southwest, and south by sedimentary rocks of the Mariposa Formation. In the lowest tongue near Elkhorn Station, the pyroclastic rocks grade rapidly from breccia to fine-grained tuff. The two overlying tongues contain breccia throughout their length of exposure in the quadrangle but have a much greater proportion of tuff than the volcanic rocks near Fowler Lookout. Subordinate rock types in the Brower Creek include pillow lava in the lower tongue exposed along Bear Creek and a mudflow deposit exposed on the north bank of the Calaveras River at the base of the upper tongue. The mudflow deposit is coarse breccia composed of fragments of oolitic limestone and volcanic rocks. The limestone was probably derived from one of the slumped blocks of Calaveras Formation that occur near this locality.

Copper Hill Volcanics

The Copper Hill Volcanics, exposed in the southwestern part of the quadrangle, overlies and intertongues with the Salt Spring Slate. The Copper Hill is the youngest known Late Jurassic formation of the western Sierra Nevada; no fossil evidence for age has been found in it but it is younger than the Salt Spring Slate and older than the Late Jurassic granodiorite near Rocklin (Curtis and others, 1958, p. 6), which intrudes it near Folsom Reservoir, north of the area of this report. The formation is probably more than 5,000 feet thick in the quadrangle but is much faulted and sheared. The formation consists largely of pyroclastic rocks but includes a thick amygdaloidal basalt flow.

Volcanic and Sedimentary Rocks of Uncertain Stratigraphic Position

Volcanic rocks of uncertain stratigraphic position (units Jvu, Jvl) but of presumed Late Jurassic age occur in two areas in the San Andreas quadrangle. A block consisting of bedded tuff and subordinate volcanic breccia in the southeastern corner of the quadrangle was included by Clark (1964, pl. 5) with the Mariposa Formation, and was mapped by Eric and others (1955, pl. 1) as phyllite and conglomerate of Jurassic(?) or Paleozoic(?) age. These volcanic rocks are interbedded with slate and conglomerate and are possibly equivalent to the Brower Creek Volcanic Member of the Mariposa Formation.

A larger area of volcanic rocks of uncertain stratigraphic position lies in a long narrow belt between the Copper Hill Volcanics and the Mariposa Formation. Shear zones form most of the northeast and southwest boundaries of this belt and occur within it; throughout its length, rocks within the belt are probably faulted against adjacent units. This unit possibly includes parts of the Copper Hill Volcanics as well as the Peñon Blanco Volcanics (Clark, 1964, pl. 6), which underlies the Mariposa Formation near Melones Dam about three miles south of the quadrangle boundary. Volcanic breccia is abundant in this belt, but amygdaloidal mafic lava occurs near Pools Station. Thin-bedded chert, which is generally very sparse in the volcanic rock units, is interbedded with pyroclastic rocks about one-half mile east of Pools Station. West of the chert exposures are small outcrops of volcanic breccia containing angular chert fragments. Tops of beds are locally westward, if, as seems probable, the chert fragments were derived by surficial processes from the beds to the east. Crumpled thin-bedded chert without interbedded volcanic rocks crops out about one mile northeast of Carmen Peak.

A narrow belt of dark-gray slate with interbedded conglomerate is apparently interlayered with the volcanic rocks near Pools Station. Conglomerate pebbles are well rounded and include felsic volcanic rocks possibly derived from the Gopher Ridge Volcanics, recrystallized chert, vein quartz, and orthoquartzite with white mica cement. Small bodies of aphanitic carbonate rocks, markedly different from carbonate rocks of the Calaveras Formation, are surrounded by, and are probably interbedded with, volcanic rocks south of Bear Mountain Ranch. Contacts are not exposed, however, and stratigraphic relations between the carbonate bodies and surrounding volcanic rocks were not established.

Sedimentary rocks of uncertain stratigraphic position extend along most of the northeast side of the Mariposa Formation from the northwest to the southeast corner of the quadrangle. They probably belong to the Mariposa Formation, but contacts are concealed, and the possibility that the older Cosumnes Formation, also of Jurassic age, is exposed in this belt has not been eliminated. Along San Domingo Creek and for about two miles southeastward, rocks of this unit contain abundant pebbles and cobbles of quartzite and arkose derived from rocks like those in the Paleozoic block along San Domingo Creek. Apparently the Jurassic rocks unconformably overlie the Paleozoic rocks, although the contact is uncertain. In this area also are bodies of carbonate rocks probably emplaced as slump blocks into the surrounding conglomerate. Near the Calaveras River, the unit is largely silty slate, but it contains interbedded tuff, graywacke, and lenticular polymictic conglomerate. A small area of quartzite that occurs along the river near the anticlinal axis may be part of the Paleozoic unit near Kentucky House that resembles the Shoo Fly Formation, but it is not differentiated on the map from the Jurassic sedimentary rocks of uncertain stratigraphic position.

Green schist (map symbol gs) derived from volcanic rocks forms an elongate body in the Melones fault zone in the central part of the mapped area, where it is associated with hornblende andesite, gabbro, and phyllite. The green schist is probably derived, in part at least, from volcanic rocks of Jurassic age but may include volcanic rocks of the Calaveras Formation. It is well exposed along California Highway 49 and along Calaveritas and San Domingo Creeks, but is poorly exposed elsewhere. In much of the green schist original textures are erased, but in places fragments of recognizable volcanic rocks suggest that it was derived from volcanic breccia. Sedimentary rocks enclosed in the green schist are chiefly phyllite, but polymictic conglomerate occurs along an abandoned railroad grade west of Carson Hill. The hornblende andesite (map symbol ha) near San Domingo Creek and along a road extending southwest from Frogtown consists chiefly of massive flows, flow breccia, and possibly some volcanic breccia (Eric and others, 1955, p. 16). Gabbroic rocks associated with the green schist are described with the intrusive rocks.

Tertiary Rocks

Tertiary rocks in the quadrangle are erosional remnants of once more widespread deposits of gravel, tuff, welded ash flows, and mudflows of volcanic debris. They are divided into alluvial gravel (auriferous gravel of earlier reports), Valley Springs Formation, and Mehrten Formation. Nearly complete sections of Tertiary rocks occur near Altaville and in the northwest corner of the quadrangle, but near the northeast corner, the Valley Springs Formation rests directly on the Calaveras Formation, and, near San Andreas and Calaveritas, gravel assigned to the Mehrten Formation directly overlies the Calaveras Formation.

Most of the Tertiary strata are related to a system of streams that drained the western Sierra Nevada during Eocene to Oligocene time. Remnants of Tertiary strata extending from the Vallecito Western mine through the Altaville and Calaveritas Hill Consolidated mines to San Andreas are related to the Central Hill channel. Tertiary rocks in the northeast part of the quadrangle are related to the ancient Central Hill channel and its tributaries, and those in the northwest part of the quadrangle, to a complex of channels that has been traced southward from Mokelumne Hill. The ancient stream channels joined near Central Hill, which is east of Latimer Gulch in secs. 2 and 11, T. 4 N., R. 11 E. (Turner, 1894; Storms, 1894; Lindgren, 1911, p. 198–212). From this point, the combined stream flowed westward and discharged a short distance north of the present channel of the Calaveras River into a gulf that then occupied the Great Valley.

The alluvial gravel is of Eocene(?) age and rests unconformably on metamorphic and intrusive bedrock. In places there is a sharp contact with the overlying Valley Springs Formation, but at other places the contact is obscured because reworked gravel is mixed with tuff of the Valley Springs Formation; at such places, the contact is drawn at the lowest level of rhyolitic tuff fragments. Most pebbles in the gravel are metamorphic rocks like those exposed in the quadrangle northeast of the Melones fault zone, but some are granitic rocks. No fragments of rock exposed southwest of the Melones fault zone occur in alluvial gravels northeast of the fault zone. Concentration of gold is generally greater near the base of the gravel than at higher levels.

Conglomerate that forms most of the colluvium near the south boundary of the quadrangle east of an arm of Melones Reservoir was included by Eric and Stromquist (pl. 1 *in* Eric, Stromquist, and Swinney, 1955) and by Clark (1964, p. 24) with the Mariposa Formation, but more recent work suggests that it is likelier to be an outlier of the alluvial gravel. Exposures do not reveal stratigraphic relations between the Mariposa Formation and the conglomerate. This conglomerate differs from conglomerate typical of the Jurassic formations in that most of the pebbles are well rounded and consist of resistant rock types, such as quartzite, vein quartz, and chert. The matrix of the conglomerate is coarse quartz sand.

In the San Andreas quadrangle, the Valley Springs Formation (Dalrymple, 1963, p. 380–382) consists of two members: a lower one of crossbedded rhyolite tuff containing gravel and sand like that of the underlying alluvial gravel, and an upper one formed by two welded ash flows separated by an alluvial rhyolite tuff containing bedrock gravel. The welded ash flows are characterized by columnar jointing, an absence of internal layering, and greater induration than the alluvial tuff. Near the northeast corner of the quadrangle, the welded ash lies directly on bedrock, indicating that it extended beyond the limits of the alluvial channels in which the bedded tuff accumulated. According to fossil and radiometric evidence summarized by Dalrymple (1963, p. 381–382), the Valley Springs Formation is of Miocene (probably middle Miocene [Hemingfordian]) age.

The Mehrten Formation occurs in the ancient Central Hill channel and in the channel complex near the northwest corner of the quadrangle. In both areas, its greatest thickness is about 300 feet. The formation consists in most places of mudflow deposits composed chiefly of andesite detritus, but it contains some bedrock fragments. In some places the formation includes alluvial-bedded sand composed of andesite grains. Gravel exposed in the Railroad Hill, Calaveritas Hill, and Ritchie Hill mines, and in an area southeast of San Andreas, consists largely of bedrock pebbles but contains pebbles of andesite and rhyolite. These gravels have been assigned to the Mehrten Formation but are possibly younger.

Piper and others (1939, p. 70–71) suggests that the Mehrten Formation is of Miocene or Pliocene age. Axelrod (1957, p. 25–28) later concluded from plant remains that the lower Mehrten is of early Pliocene (early Clarendonian) age. Dalrymple (1963, p. 384) suggests, on the basis of potassium-argon dates, that the upper part of the Mehrten is of Pliocene (Hemphillian) age.

Quaternary Deposits

Quaternary deposits include alluvium in modern streams, placer mine tailings, and slope debris resulting from landslide and other mass-wastage processes. Along modern streams, the distinction between alluvial gravels and placer mine tailings has little significance, because tailings in streambeds are commonly redistributed by the streams during the wet season. Colluvium on some of the steeper slopes in the quadrangle results in part from landslides and in part from the breaking of individual blocks from steep slopes. Most of the colluvium shows no evidence of recent movement, but in 1958 the recent addition of a single boulder about six feet long to the colluvium in sec. 27, T. 4 N., R. 11 E., was indicated by freshly broken and scarred trees, and by fresh impact marks on the ground.

INTRUSIVE ROCKS

Intrusive rocks, presumably of Late Jurassic and Cretaceous age, include hypabyssal intrusive rocks (Jh) of altered mafic porphyritic rocks as well as plutonic ultramafic rocks (Ju), diorite (KJd), and granodiorite (KJg). Gabbroic rocks (Kjh) of diverse origin are included in this section for convenience. Too small hypabyssal intrusives occur in the Mariposa Formation in the west-central part of the quadrangle, and, to the west, a larger body intrudes the Copper Hill Volcanics and serpentine. The hypabyssal intrusives, possibly related genetically to the Jurassic extrusive rocks, consist of saussuritized plagioclase, pyroxene, chlorite, quartz, carbonate, and grains too small to be identified even under the microscope. The two larger intrusives contain plagioclase phenocrysts, and the largest also contain, in places, phenocrysts of amphibole or pyroxene. Contact metamorphism caused recrystallization of the Copper Hill Volcanics near the margin of the largest intrusive, particularly at its southwest end and in sec 11, T. 3 N., R. 11 E.

Gabbroic rocks occur in several different geologic settings in the quadrangle: in the green schist unit, where they are possibly of metamorphic origin; in the southern border part of the felsic pluton southeast of San Andreas; as small intrusives near Mountain Ranch; and as dikelike bodies in the serpentine about one mile north of Carmen Peak. Gabbro bodies extending about two miles south from Angels Camp are probably of metamorphic origin: they are variable in texture throughout and in many places grade texturally into the surrounding green schist. Pods of gabbroic rock as small as two feet long and a few inches thick are enclosed in the green schist in the northwest part of Angels Camp. Gabbroic rocks in the southern marginal part of the felsic pluton southeast of San Andreas, not subdivided on plate 1, grade through intermediate rock types into the parent granodiorite of the pluton. Gabbro that forms dikelike bodies in serpentine about one mile north of Carmen Peak is possibly in part intrusive, but, in one place, grades from pyroclastic texture to gabbro texture within a distance of about six feet, a fact that suggests the gabbro was formed by metamorphism of volcanic rock inclusions in the ultramafic intrusive.

Ultramafic rocks and metamorphic rocks derived from them occur throughout the quadrangle. Most bodies are elongate parallel to cleavage and shear zones in the surrounding metamorphic rocks. According to Cater (1948, p. 38), most of the ultramafic rocks in this part of the western Sierra Nevada were originally saxonite, but some were dunite or pyroxenite. Most of the original rocks were altered to serpentine, and, northeast of the Melones fault zone, were further altered to talc-ankerite-antigorite schist. Some schist bodies retain cores of serpentine, and in sec. 2, T. 3 N., R. 13 E., some chromite-bearing ultramafic rock is only slightly altered. As most of the ultramafic rocks are in shear zones, it may be that some bodies, such as those in the western part of the Copper Hill Volcanics, were detached from larger, older intrusions at depth and were faulted or intruded as serpentine into their present positions. The ultramafic rocks are of Late Jurassic age, for they intrude the Upper Jurassic Copper Hill Volcanics, which are in turn cut northeast of Folsom (fig. 1) by granodiorite of Late Jurassic age (Curtis and others, 1958, p. 6). Within the quadrangle, ultramafic rocks or their metamorphic derivatives are truncated by the granodioritic pluton near Calaveritas and are intruded by small plutons of diorite and granodiorite near the south map boundary.

A diorite pluton intrudes the Mariposa Formation about three miles southwest of San Andreas. Its contact is poorly exposed in most places, but a chilled border zone shows along a creek in the SW¼, sec. 36, T. 4 N., R. 11 E. A smaller diorite body is surrounded by serpentine near the south boundary of the quadrangle. Diorite forms dikes in Paleozoic rocks near Kentucky House, very small bodies in unnamed sedimentary rocks northwest of San Andreas, and unmapped fine-grained dikes a few inches to about 15 feet thick in joints north of Mountain Ranch, as well as larger bodies.

A small granodiorite mass, mostly hidden by colluvium, is bounded by serpentine and the Copper Hill Volcanics near the south boundary of the quadrangle. Southeast of San Andreas, a larger pluton is in a steeply northeast-plunging structural trough defined by schistosity in the Calaveras Formation. Most of the granodiorite is uniform, but near its margins, compositions range from hornblende gabbro to granodiorite. These mixed rocks evidently result from reaction of the granodiorite magma with mafic wall rocks at depth, for contact metamorphic effects on the siliceous Calaveras Formation are barely discernible.

STRUCTURAL GEOLOGY

Major Structures

The rock structure in the San Andreas quadrangle resulted from three stages of deformation: during late Paleozoic or early Mesozoic time, an eastward-trending anticline in the east-central part of the mapped area was formed in rocks of the Calaveras Formation; during late Jurassic time, slip cleavage and minor folds were formed in the Calaveras Formation, and the Jurassic rocks were first folded, and then faulted, along two northwest-trending reverse fault zones. Each deformation is marked by linear and planar minor structures having distinctive orientations.

FAULTS

The Melones and Bear Mountain fault zones and the shear zone in the northeast part of the quadrangle are parts of a great reverse fault system that has been traced from the Merced River to the north end of the Sierra Nevada. In most places the fault zones are nearly vertical, but in the San Andreas quadrangle they dip about 75° northeastward. Lineations in the fault zones plunge steeply and are parallel to axes of crinkles on slip surfaces. Accordingly, the lineations are parallel to the *b* tectonic axis and indicate a dominant horizontal component of movement. Nevertheless, strike-slip fault movement is not necessarily entirely responsible for the large stratigraphic separations indicated by the present distribution of metamorphic rocks in the western Sierra Nevada.

Along the Melones fault zone, which extends across the quadrangle from the southeast to the northwest corner the Calaveras Formation is juxtaposed against Upper Jurassic strata with pronounced structural discordance. Along the Bear Mountains fault zone to the southwest, the Copper Hill Volcanics on the southwest side of the zone are separated from the older Mariposa Formation by a narrow, fault-bounded belt of volcanic rocks of uncertain stratigraphic position. Each fault zone embraces a wide belt of individually mappable shear zones, faults, and less readily defined belts of schist. Many individual shear zones and faults are observable in the Bear Mountains fault zone because the rocks, with a few exceptions, retain their original textures and structures. On the other hand, much of the Melones fault zone is occupied by green schist in which individual faults are unrecognizable. Described later in this report are faults that control the quartz veins with which the Mother Lode ore deposits in the quadrangle are associated. These faults are within the Melones fault zone but are younger and apparently independent structures. Northeast-trending cross faults, inferred by Eric and others (1955, pl. 1) in the Melones fault zone could not be confirmed during the present investigation.

Two belts in the Calaveras Formation are probably loci of considerable movement. A northwest-trending shear zone about one mile southwest of Mountain Ranch is marked by pronounced schistosity and by elongate lenses of talc-ankerite-antigorite schist. A broader, ill-defined shear zone is suggested by segments of faults and by elongate lenses of talc-ankerite-antigorite schist extending from Calaveritas to the eastern boundary of the map. Near Calaveritas, the shear zone swings northwestward around the granodiorite pluton.

FOLDS

The chief folds are in the Calaveras Formation near Calaveritas, and in Jurassic rocks between the Bear Mountains fault zone and the green schist in the Melones fault zone. Top directions and bedding attitudes southeast of the Bear Mountains fault zone suggest that there the section is essentially homoclinal, although small folds might be present in the Salt Spring Slate. Southwestward dips near Carmen Peak may be in large rotated slumped blocks, but, even if in place, the attitudes indicate but a small area of southwestward dip.

The complex eastward-trending fold near Calaveritas is indicated by the outcrop pattern of the metavolcanic member, and its anticlinal character is shown by graded beds about three miles east of Calaveritas, showing that tops of beds are toward the north. Bedding shows in but a few places along the anticline, and the dip of fold limbs is possibly much less steep than indicated in the structural cross section (pl. 1), where color boundaries mark contacts between map units and the black pattern indicates structure. Smaller anticlines may occur at exposures of the volcanic member of the Calaveras Formation one to three miles north and west of the Vallecito Western mine.

An almost isoclinal syncline, with an axial surface dipping northeast about 75°, occupies most of the space between the Melones and Bear Mountains fault zones. In the northern part of the quadrangle the syncline is simple, though faulted, and the trace of its axial surface is established, but southwest of Angels Camp the syncline is more complicated, as indicated by minor folds and reversals in top directions. An anticline is indicated by opposing top directions in the discontinuous easternmost exposed belt of the Brower Creek Volcanic Member of the Mariposa Formation in the southeastern part of the quadrangle. The asymmetric position of the anticline in the outcrop belt of the volcanic member, however, suggests that the northeastward top direction reflects only a minor fold. Another anticline, faulted along at least part of its western border, was formed in sedimentary rocks of uncertain stratigraphic position in the northwestern part of the mapped area. Gently plunging minor folds and nearly horizontal intersections of slaty cleavage and bedding, not shown on the map, indicate that axes of major folds in the Jurassic rocks are about horizontal.

Minor Structures

Two metamorphic planar structures, schistosity and slip cleavage, occur in the Calaveras Formation. Schistosity, in most places the older of the two, ranges widely in attitude and is readily observed throughout the area underlain by the Calaveras Formation. The slip cleavage is of more constant attitude and shows best near Calaveritas, where orientations of the two structures differ markedly; farther north and northeast, where they are nearly parallel, only schistosity is found. The slip cleavage is nearly parallel and probably related to schistosity in the Melones fault zone, as is the dominant schistosity in the Calaveras Formation southeast of Angels Camp. Here, traces of a deformed older schistosity suggest that the more prominent schistosity is superimposed.

Bedding is rarely preserved in the Calaveras Formation. It is most evident near the east-trending belt marked by the volcanic member of the Calaveras Formation. In the much larger area underlain by the interbedded chert and phyllite of the Calaveras Formation, bedding is but rarely preserved, and, where seen,

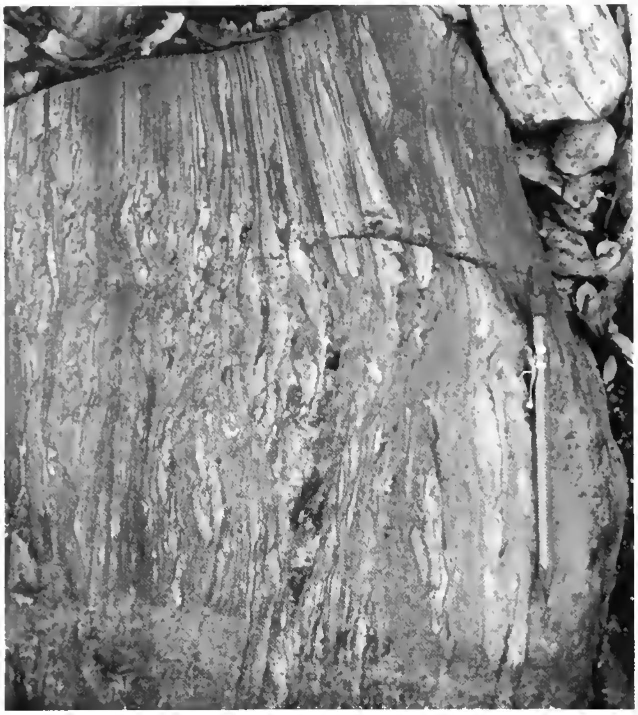


Figure 6. Chert Fragment Lineation. The lineation, in the Calaveras Formation, is nearly horizontal. White areas are chert and dark areas are quartzose graphitic phyllite. The lower part of the photograph is a nearly vertical face showing ends of linear elements; upper part of photograph is a foreshortened view of a nearly horizontal surface showing long dimension of linear elements.

bedding is parallel to schistosity, suggesting that only in this orientation was it saved from destruction by shearing. If so, bedding in such small areas would provide no useful information on the general attitudes of beds. Slaty cleavage is approximately parallel to the axial surfaces of folds in most of the Jurassic sedimentary rocks; a similar cleavage is developed in most of the Jurassic volcanic rocks, but only in weathered outcrops is it readily visible.

Lineations in the San Andreas quadrangle formed parallel to major or minor fold axes or to crinkles on slip surfaces during at least two stages of deformation. They are of several different kinds: lineation in the nonschistose Jurassic rocks is defined by the intersection of slaty cleavage and bedding, and one kind of lineation in the Calaveras Formation is defined by the intersection of slip cleavage and schistosity. A more ubiquitous lineation in the Calaveras Formation consists of elongate fragments of chert beds (fig. 6). This lineation is in places accompanied by one or more sets of tiny crenulations on schistosity surfaces, one set locally coinciding with the intersection of slip cleavage and schistosity. Chert fragment lineations in the Calaveras Formation lie in the plane of schistosity and are parallel to a set of minor fold axes. In some places the chert fragments are cigar shaped, but more commonly they are flattish, and their edges range from sharp to bluntly rounded. Thin elongate mica pods lie in pressure shadows of some chert fragments.

Lineations in schistose rocks of the major fault zones consist of elongate rock fragments, pods of calcite, axes of crinkles on slip surfaces, and intersections of anastomosing slip surfaces. Regionally, these lineations are parallel to amphibole alignment in sheared granitic rocks near the Cosumnes River (Clark, 1964, p. 57) and in amphibolite near the American River northwest of Placerville (fig. 1). The lineations plunge almost directly down the dip of fault zone schistosity and are parallel to the *b* tectonic axis, which is the axis that lies in the shear plane and is normal to the direction of movement.

Comparison of the orientations of minor structures in the Calaveras Formation with those of the Melones fault zone confirms the suggestion of the map pattern that the anticline extending eastward from Calaveritas is older than the Melones fault zone. The slip cleavage, which is nearly parallel to schistosity in the Melones fault zone and is interpreted to be of the same age, cuts a previously folded schistosity in the Calaveras Formation. Chert-fragment lineation in the vicinity of the anticline is about parallel to the anticlinal axis and was formed during development of the anticline. It diverges about 15° or 20° from the orientation of fault zone lineation.

ECONOMIC GEOLOGY

Asbestos

Chrysotile asbestos occurs in stockworks of cross-fiber veinlets in serpentine. Fibers as long as $\frac{3}{16}$ inch occur in sec. 2, T. 3 N., R. 13 E., but most fibers are shorter. Similar chrysotile occurs at the Turner and Lloyd exploration in sec. 15, T. 2 N., R. 12 E., and in some other serpentine bodies. Actinolite or tremolite asbestos forms a vein about one foot thick 200 feet west of the triangulation station in sec. 1, T. 3 N., R. 13 E. The fibers are parallel to vein walls and fiber length is independent of wall thickness.

Chromite

Chromite deposits in the quadrangle are restricted to the ultramafic rocks, where they occur as pods or irregular lenses in dunite, which in turn is surrounded by sheared serpentine. High-grade ore, commonly described as massive ore, consists of closely packed, nearly pure aggregations of chromite grains; low-grade ore consists of separate chromite grains disseminated in a matrix of olivine or serpentine (Cater, 1948, p. 10). Some low-grade ore consists of alternating thin layers and clots of nearly pure chromite and nearly barren dunite (Cater, 1948, p. 39). Small amounts of uvarovite, a chrome garnet, and kämmererite, a chrome chlorite, occur in some deposits, but chromite is the only mineral of economic interest. Chromite, a member of the spinel isomorphous series of minerals, ranges widely in composition; the amount of chromium in chromite ranges from more than 61 percent to less than 30 percent (Stevens, 1944, p. 24).

Chromite mining in this region probably began in the 1890's, and reached its peak during World War I, but after the end of the war, production ceased; it was revived on a small scale during World War II (Cater, 1948, p. 37). Within the quadrangle, most of the ore was recovered from mines near the central part of the south border of the quadrangle, and from the Madrid mine in the SW¼ sec. 2, T. 3 N., R. 13 E. The reported total production of chromite ore (Cater, 1948, p. 46–48, 56–57) is 2,173 long tons, of which nearly half was yielded by the Madrid mine.

Copper

Although some copper has been produced from the San Andreas quadrangle, the character of productive deposits is best illustrated by more thoroughly studied mines at Copperopolis, about 1½ miles south of the quadrangle boundary, and at Quail Hill, about three miles south of the boundary. At these mines the copper ores are steeply plunging lenticular massive sulfide replacement deposits in shear zones (Heyl, 1948, p. 1922). The sulfides commonly replaced chloritized metavolcanic rocks, but they also replaced chloritized granodiorite and slate (Heyl, 1948, p. 104). The chief primary sulfide minerals are pyrite and chalcocite, but pyrrhotite, galena, tetrahedrite, sphalerite, bornite, magnetite, ilmenite, gold, and silver have been reported (Heyl, 1948, p. 20). Chalcocite is the chief secondary copper mineral, but except in near-surface zones of secondary enrichment, which were depleted soon after their discovery in 1860, secondary minerals have accounted for but a small fraction of production and seldom occur at depths greater than 160 feet (Heyl, 1948, p. 23).

Massive sulfide ore was produced from the Nassau mine in the northwest corner of sec. 10, T. 2 N., R. 12 E. The mine is reported to have produced, by 1908, about $70,000 in ore containing about 0.2 oz. gold, 4.6 oz. silver, 5.2 percent copper, and 17.9 percent zinc per ton (Aubery, 1908, p. 245). The mine has since been inactive except for dewatering in 1941.

The shear zone marked by sporadic lenses of serpentine that extends N. 35° W. from sec. 28, T. 2 N., R. 12 E., is a continuation of the zone in which the Copperopolis ores occur, and, with modern exploration technology, might yield new ore discoveries. The entire segment of the zone that lies within the San Andreas quadrangle was covered by claims in 1867 (Jenkins, ed., 1948, pl. 34), but prospecting during the early 1860's was spurred chiefly by residual gold in the gossan cappings of sulfide ore bodies and by near-surface secondarily enriched copper ores (Heyl, 1948, p. 13). Records contain no assurance that this shear zone has been adequately explored at depth within the quadrangle.

The few copper mines or explorations in the northeastern half of the quadrangle are in a different geologic environment than those to the southeast, but few details of their occurrence are known. Copper ore was reportedly produced before 1914 from the Bonanza mine in the Calaveras Formation near the North Fork of Murray Creek in secs. 27 and 34, T. 5 N., R. 12 E. (Eric, 1948, p. 218). Copper mineralization associated with serpentine was explored near the Madrid chromite mine in sec. 2, T. 3 N., R. 13 E., and at the Bund mine in sec. 12, T. 3 N., R. 12 E.

Gold

Lode mines in the quadrangle are reported to have produced almost $54 million in gold, nearly all of which was sold at $20 per troy ounce. Total production is substantially greater, for much of the yield during the active mining period extending from 1850 to 1894 was not recorded; later production data were tabulated by counties and do not identify the output of individual mines. Consequently, of the 35 mines in the quadrangle that are described by Clark and Lydon (1962, p. 40–74), production figures are available for only nine, and most of these figures are minimum values derived from incomplete records. Lode gold was obtained mostly from the Mother Lode belt, which extends across the quadrangle from the southeast corner to near the northwest corner, but mines distributed throughout much of the quadrangle on both sides of the Mother Lode have contributed to the total production.

Areas northeast and southwest of the Mother Lode are known, respectively, as the "east gold belt" and "west gold belt", but the distribution of mines within these areas fails to delineate consistently a beltlike arrangement. Within the quadrangle, more than 80 gold mines and explorations, not all shown on the map, are in veins of the east gold belt (Clark, 1954, p. 20–21; Eric and others, 1955, pl. 3). Few of these are developed by as much as 1,000 feet of workings, but small bodies of very rich ore were reportedly found in some mines. Within the quadrangle, the greatest concentration of east-belt mines and prospects is in an area extending from about four miles east of Calaveritas to the east quadrangle boundary. In the west gold belt, mines are sparse, but near the south quadrangle boundary are two important gold mines, the Mountain King and the Royal. Their total reported production of $4 million (Clark and Lydon, 1962, p. 64; Knopf, 1929, p. 72) was obtained from quartz veins and replacement deposits in the Copper Hill Volcanics. Geologically, these deposits are similar to those of the Mother Lode described below.

The Mother Lode, described during the excitement of early discoveries as a single great lode more than 100 miles long, proved subsequently to be a discontinuous belt about one to two miles wide of veins and replacement deposits (Knopf, 1929, p. 5, 24). Most of the large veins dip steeply northeastward, but other veins dip gently. Within the quadrangle and throughout much of its extent, the Mother Lode coincides with the longer and more persistent Melones fault zone, but the two are not identical. Knopf (1929, p. 24) observed that, in the large mines that he studied, Mother Lode quartz veins cross schistosity of the sheared rocks, and other deposits replace sheared rocks within the structure here called the Melones fault zone. He concluded: "These fissures appear to be auxiliary fissures in a great reverse fault that bounds the Mother Lode on the east" (Knopf, 1929, p. 48). The two generations of structures are readily distinguishable at Carson Hill in the southeast corner of the quadrangle, where detailed mapping by Eric and Stromquist (*in* Eric, Stromquist, and Swinney, 1955, pl. 1) shows that serpentine and schist contacts that parallel Melones fault zone schistosity are offset along Mother Lode reverse faults. Existing information on the age of lode-gold ores, however, is derived from studies of large deposits in mines having extensive workings. It does not preclude the possibility that some smaller ore bodies were formed during active Melones fault zone movement but have not yet been studied in sufficient detail to establish their age.

Although Knopf (1929, p. 45) established that Mother Lode veins are related to reverse faults, he found evidence for lateral movement also (Knopf, 1929, p. 25). At Carson Hill, where gently dipping as well as steeply dipping veins occur, the attitudes of veins and of markings on their surfaces indicate diverse movements. Near the top of Carson Hill, the thick quartz vein, known as the Bull vein, that separates the footwall and hanging-wall glory holes of the Morgan mine strikes N. 45° W. and dips 35° SW. Small gash veins in the wallrock of the hanging-wall glory hole strike N. 15 W. and dip 35° SW. The projected intersection of gash veins with the Bull vein plunges about 30° W. at an angle of 20°. Polished flutings or mullions, prominent on surfaces of the sheeted quartz that constitutes the Bull vein (fig. 7), are apparently parallel to the direction of movement and plunge S. 85° E. at an angle of 35°. Wavelike rolls on the surface of the vein are normal to the fluting and plunge N. 15° W. at an angle of about 33°. Steep sides of the waves are downward and are on the stoss or "upstream" side if the Bull vein is in a reverse fault. The quartz vein at the Santa Cruz opencut of the Calaveras mine, near California Highway 49 near the east boundary of the mapped area south of Carson Hill, strikes N. 25° W. and dips 60° NE. Flutings on the surface of the vein plunge S. 65° E. at 45°.

Mother Lode quartz veins, according to Knopf (1929, p. 24–28), range widely in thickness, and gold may be uniformly distributed across a vein or limited to a part of it. In general, ore shoots plunge steeply and are much shorter than the veins in which they occur. Most veins are accompanied by gouge, but no gouge is associated with the Bull vein at Carson Hill, which is the largest vein in the area. Free gold, together with pyrite and arsenopyrite that contain free gold, occur in massive vein quartz, in slate partings in ribbon quartz, in wallrock inclusions in quartz veins, and in some places, in gouge. Uraninite occurs in quartz at the Union-Rathgeb mine (Rathgeb mine on pl. 1), but not in economic quantities.

Replacement deposits in metavolcanic rocks along the Mother Lode and in the southwestern part of the quadrangle constitute the largest ore deposits in the quadrangle. Replacement ore formed in schistose metavolcanic rocks is similar mineralogically to that formed in massive metavolcanic rocks, but in the latter, the original clastic texture is preserved in fine detail, even though the original rocks are completely changed chemically. Ore in which the original texture is so preserved is known as "gray ore." Replacement deposits occur in the footwall, hanging wall, or both, of quartz veins, but no fixed relation of the size of an ore deposit to thickness of associated veins is apparent. Knopf (1929, p. 33) suggested that the most favorable site for replacement is in the wedge ends of country rock between converging fissures. Replacement ore bodies consist chiefly of ankerite, but contain pyrite, sericite, quartz, albite, and accessory rutile (Knopf, 1929, p. 32–33). Some molybdenite occurs at Carson Hill and near Angels Camp. Copper, lead, zinc, and silver minerals occur in places along the Mother Lode as well as in some mines of the east and west gold belts. Mariposite occurs in ankerite at Carson Hill, but is much less abundant there than farther south along the Mother Lode.

Placer-gold production in the western Sierra Nevada as a whole exceeds that of lode gold, but whether this holds true in the San Andreas quadrangle is uncertain, for placer production records are even less adequate than those of lode mines. Within the quadrangle, placer gold was recovered from modern streams, including their steep intermittent tributaries, and from Tertiary river-channel deposits in the alluvial gravel and Mehrten Formation.

The Tertiary streams generally flowed south or southwest (see Clark and Lydon, 1962, fig. 11, p. 81), with the exception of a Central Hill channel segment in which flow was northwestward from the Calaveras Central mine near Altaville to a point about two miles northwest of San Andreas. Gold that accumulated in the Tertiary channel deposits was derived largely from areas northeast of the Mother Lode. Consistent with this interpretation is the fact that pebbles of rocks characteristic of the Mother Lode belt and areas to the southwest are absent in channels northeast of the belt. Both modern and Tertiary placer deposits, however, are reported to have been richer downstream from the Mother Lode. An excellent description of placer deposits and mining methods is given by Clark and Lydon (1962, p. 76–93).

Limestone

Limestone deposits in the quadrangle provide the basis for its chief present-day (1967) mineral industry, namely, the manufacture of cement by the Calaveras Cement Company at Kentucky House. Limestone used to date was obtained chiefly from a quarry in the Calaveras Formation about one mile northeast of Calaveritas, and from a group of quarries near Kentucky House in limestone of uncertain stratigraphic position. The largest carbonate rock body in the area, extending southeast from Mountain Ranch, has not yet been exploited because of distance from the plant

Figure 7. Surface of Bull Vein. This face of Bull vein appears in the hanging-wall glory hole of the Morgan-Melones mine at Carson Hill. Cross-hatch pattern on vein results from polished flutings plunging downward to the left (SE) and wavelike rolls plunging downward to the right (NW). Waste dump in left foreground.

and unfavorable calcium-magnesium ratios in part of the body (Clark and Lydon, 1962, p. 102–103). Some of the elongate carbonate rock lenses in a belt extending eastward from Calaveritas are possible sources of limestone, but one body is in part replaced by ferruginous chert and another is metamorphosed to tremolite-bearing coarse crystalline limestone (Clark, 1954, p. 17).

Most limestone blocks in the Jurassic strata were emplaced by slumping and offer little encouragement for development of large deposits, although old quarries suggest that some of these blocks were used, probably during the 19th century, for stucco and mortar. Bodies of very fine grained, almost lithographic limestone interbedded with volcanic rocks southeast of Pool's Station also appear to be small, but possibly are larger than indicated on the map.

Manganese

Small manganese deposits are interbedded with schist and metamorphosed chert in the Calaveras Formation and with red chert and tuff in the Copper Hill Volcanics. In the Calaveras Formation, the primary manganese minerals are silicates (Trask, *in* Trask and others, 1943, p. 75); rhodonite and spessartite occur at the Airola mine in sec. 35, T. 3 N., R. 12 E., but only spessartite was identified at the Fortner Ranch Mine in sec. 4, T. 4 N., R. 12 E. In the Copper Hill Volcanics, the most common primary manganese mineral is rhodonite, which occurs in sec. 24, T. 3 N., R. 11 E., and in sec. 4, T. 2 N., R. 11 E., but bementite, a hydrous manganese silicate, is also present (Trask, 1943, p. 76). Both carbonate and silicate ores are in part oxidized to psilomelane and pyrolusite.

Silica

Alluvial sand and gravel in the quadrangle have been little used for silica because larger deposits nearby meet current demands more economically. However, quartz veins near Carson Hill that are as much as 40 feet wide and are little contaminated by metallic minerals may warrant investigation as a source of silica (Clark and Lydon, 1962, p. 107).

Stone

Most, if not all, varieties of rock in the quadrangle have been utilized locally for construction or decorative purposes, but the kinds exploited commercially are more limited. White welded volcanic ash of the Valley Springs Formation one mile northeast of Altaville is quarried intermittently for light-weight aggregate and roofing granules; in the past it was utilized as a durable, easily dressed, low-density building stone. The welded ash is also suitable for decorative facing material. Some Jurassic tuff has been used for roofing granules, and silty slate in the Salt Spring Slate and Mariposa Formation can be used for roofing granules and for slabs to pave walkways and terraces. Stone and construction materials are discussed in greater detail by Clark and Lydon (1962, p. 109–120).

Talc

Talc deposits in the area have been utilized only locally and in small amounts for refractory furnace lining. Massive talc occurs in the ultramafic body in sec. 2, T. 3 N., R. 13 E., and at the quadrangle boundary two miles east of Angels Camp. Specimens of high-grade talc are reported to have been collected from the Wheeler mine (Thomas Brothers Group). White talc occurs in the deposit east of Angels Camp. Much more abundant schistose talc, bearing impurities such as iron oxide, antigorite, and ankerite, occurs throughout much of the eastern part of the quadrangle and is a potential source of industrial talc if suitable beneficiation procedures can be developed.

Tellurides

Tellurides of silver, gold, nickel, lead, and antimony, as well as native tellurium, occur at Carson Hill, but unfortunately, most of the tellurides were lost in attempts to recover the gold in them. The tellurides include petzite, calaverite, hessite, sylvenite, altaite, melonite, and nagyarite. Tellurides also occur at the Ford mine, near San Andreas, and at the Bence mine, five miles east of Calaveritas; native tellurium is reported to have been found near Angels Camp (Clark and Lydon, 1962, p. 120–121).

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THIS BOOK IS DUE ON THE LAST DATE

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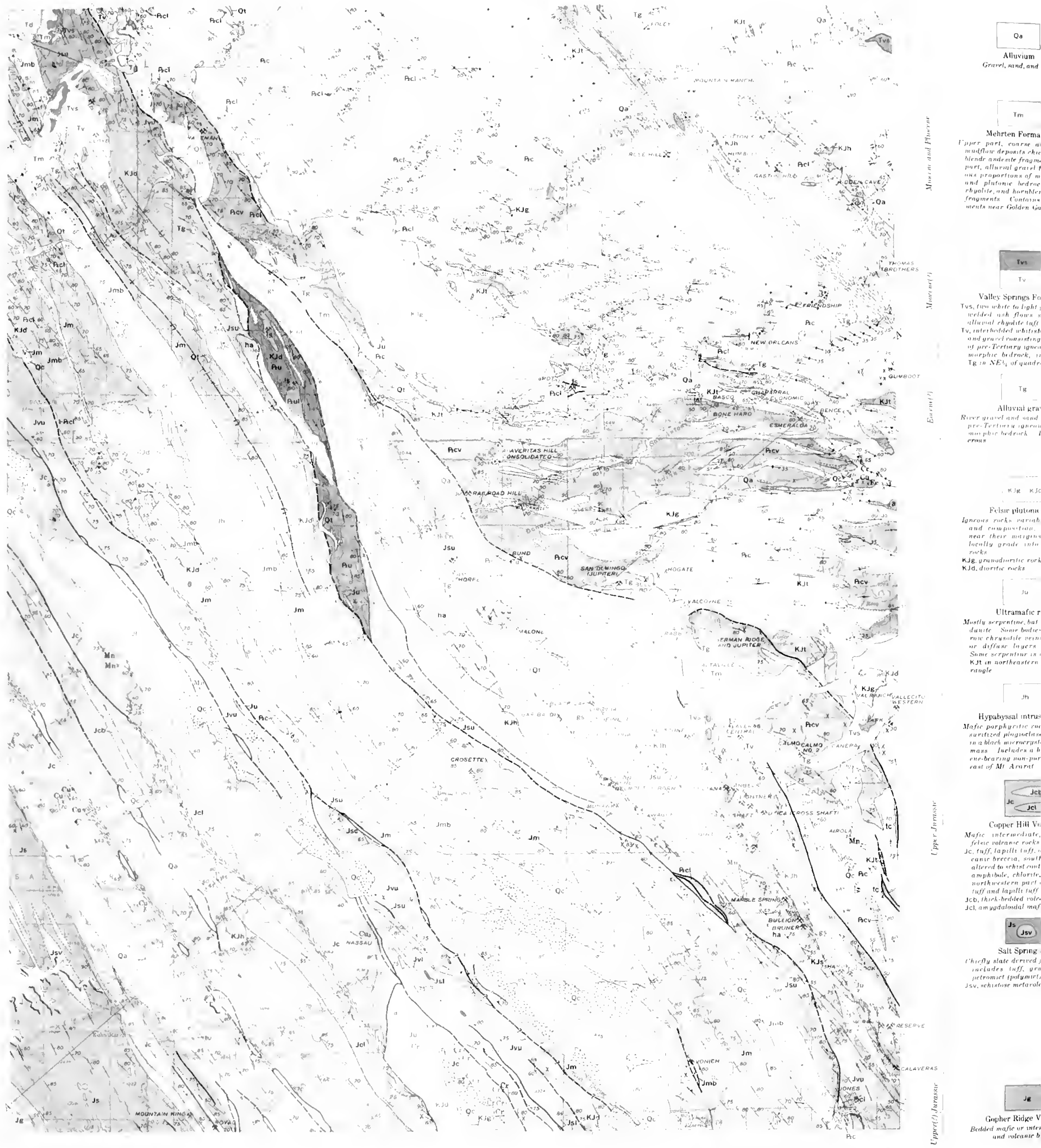
Collate 1 Map

GEOLOGY OF THE
SAN ANDREAS QUADRANGLE
CALIFORNIA
GQ-222

BULLETIN 195
PLATE 1

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

PREPAPED IN COOPERATION WITH
CALIFORNIA DIVISION OF MINES AND



Base map by Topographic Division
U.S. Geological Survey 1945

Mapped in 1946–58. Southeast quarter revised from Eric and others, 1955, plate 1 (Eric and Stromquist)

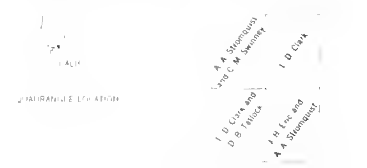
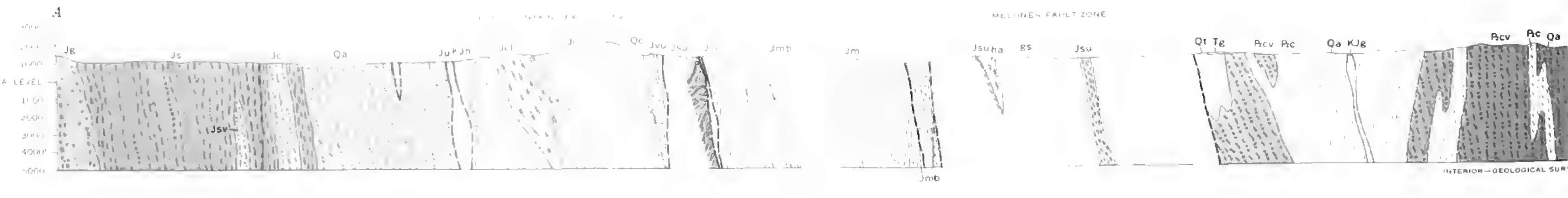


DIAGRAM SHOWING RESPONSIBILITY FOR
ORIGINAL MAPPING AT SCALE 1:24,000



GEOLOGY OF THE
SAN ANDREAS QUADRANGLE
CALIFORNIA
GQ-222

GEOLOGIC MAP OF THE SAN ANDREAS QUADRANGLE, C

By

Lorin D. Clark, Arvid A. Stromquist, and Donal

1963

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INES AND GEOLOGY

GEOLOGY OF THE
SAN ANDREAS QUADRANGLE
CALIFORNIA
GQ-222

BULLETIN 195
PLATE 1

EXPLANATION

QUATERNARY

Qa

Alluvium
Gravel, sand, and clay

Qt

Tailings
Derived from placer and hydraulic mining of Tertiary and Quaternary gravels. Included with Qa in NE¼ of quadrangle

Qc

Colluvium
Debris resulting from landslides and other mass wastage processes

TERTIARY

Tm

Mehrten Formation
part; coarse alluvial and ow deposits chiefly of horn- andesite fragments. Lower alluvial gravel having vari- roportions of metamorphic plutonic bedrock, Tertiary te, and hornblende andesite ents. Contains dacite frag- near Golden Gate Hill

Td

Dacite plug
Gray and brown fragmental porphyritic hornblende-biotite dacite (Rose, 1959, p. 14). Exposed only at Golden Gate Butte

Tvs
Tv

y Springs Formation
hite to light gray rhyolite ash flows separated by rhyolite tuff
dded whitish rhyolite tuff el consisting of fragments rtiary igneous and meta- bedrock, included with E¼ of quadrangle

Tg

Alluvial gravel
el and sand derived from iary igneous and meta- bedrock. In pa t aurif-

ANGULAR UNCONFORMITY

Volcanic and sedimentary rocks below are deformed and metamorphosed

JURASSIC AND CRETACEOUS

KJg KJd

lsic plutonic rocks
ocks variable in texture nposition, particularly ir margins, where they grade into more mafic
dioritic rocks
ic rocks

KJh

Gabbroic rocks
Medium- to coarse-grained hornblende gabbro. Consists chiefly of saussuritized plagioclase and hornblende

KJt

Talc-bearing schist
Schist composed chiefly of ankerite and talc in various proportions. Some bodies also contain antigorite and pyrite. Includes some calcite-chlorite-muscovite schist and serpentine

KJs

Quartz-ankerite-sericite schist

JURASSIC

Ju

Jltramafic rocks
pentine, but includes some Some bodies contain nar- ysotile veinlets and pods ise layers of chromite rpentine is included with ortheastern part of quad-

Jh

oyssal intrusive rocks
phyritic rock with saus- d plagioclase phenocrysts k microcrystalline ground- Includes a body of pyrox- ing non-porphyritic rock Mt Ararat

Jc Jcb Jcl

pper Hill Volcanics
termediate, and sparse lcanic rocks
apilli tuff, and some vol- reccia, southwestern part to schist containing fibrous ole, chlorite, and epidote, astern part chiefly bedded ' lapilli tuff
-bedded volcanic breccia
laloidal mafic lava

Jvl Jvu

Volcanic rocks of uncertain stratigraphic position
Mafic or intermediate bedded tuff and volcanic breccia, possibly equivalent in part to other volcanic units in the map area or to the Piñon Blanco Volcanics to the south
Jvl, mafic lava

Jsc Jsl Jsu

Sedimentary rocks of uncertain stratigraphic position
Mostly slate, possibly in part tuffaceous, with some interbedded tuff and graywacke. Lenticular petromict conglomerate abundant northwest of San Andreas and west of Bernasconi Ranch. Contains large slumped blocks of Paleozoic rocks in some places. Possibly in part equivalent to Mariposa Formation or Cosumnes Formation
Jsc, interbedded chert and slate
Jsl, massive white aphanitic limestone lenses

Js Jsv

Salt Spring Slate
ate derived from siltstone, is tuff, graywacke and ct (polymict) conglomerate tose metavolcanic rock

Jm Jmb

Mariposa Formation
Chiefly slate, tuff, and graywacke, petromict conglomerate abundant west and south of Deer Peak, metachert and quartzose slate abundant southwest of Hogback Mountain. Locally contains large slumped blocks of Calaveras Formation
Jmb, Brower Creek Volcanic Member, very coarse, heterogeneous volcanic breccia in vicinity of Fowler Lookout, elsewhere ranges from very fine tuff to coarse breccia; contains pillow lava near Bear Creek

Jg

pher Ridge Volcanics
mafic or intermediate tuff and volcanic breccia

PALEOZOIC(?) AND MESOZOIC

gs ha

Green schist and related rocks
gs, green schist derived from basaltic and andesitic breccia and tuff, consists largely of saussuritized feldspar and actinolite with some epidote, clinozoisite, chlorite, and sericite, possibly in part equivalent to volcanic rocks of the Calaveras Formation
ha, porphyritic flows and flow breccias, contains minor hornblende dacite

PALEOZOIC

Pzc Pzcl
Pzcv

Calaveras Formation
Pzc, mostly interbedded chert and graphitic phyllite and schist but includes lenticular basaltic or andesitic volcanic rocks, and, possibly minor orthoquartzite, probably in part of Permian age
Pzcl, recrystallized limestone and dolomitic limestone
Pzcv, pyroclastic rocks, commonly bedded, having mineralogy similar to that of the green schist

Pzu Pzul

Sedimentary rocks of uncertain stratigraphic position
Quartz-rich sedimentary and, possibly, volcanic rocks including graywacke or tuff, and phyllite with subordinate interbedded arkose and orthoquartzite. Resembles Shoo Fly Formation of northern Sierra Nevada. Northern block possibly includes other stratigraphic units
Pzul, recrystallized limestone and dolomitic limestone

Contact
Dashed where approximately located, short dashed where inferred

Fault
Dashed where approximately located, queried where inferred

Shear zone

FOLDS

Erect *Overturned*
Trace of axial surface of major syncline

Approximate trace of axial surface of major overturned anticline

Quartz vein

PLANAR FEATURES

Inclined *Vertical* *Overturned* *Generalized strike and dip of crumpled beds*
Strike and dip of bedding
Overturned bedding symbol used only where top determinations were made

Parallel bedding and cleavage

Vertical *Inclined*
Slaty and phyllitic cleavage

Vertical *Inclined*
Slip cleavage

Vertical *Inclined*
Schistosity

Vertical *Inclined*
Joints

DIRECTIONAL FEATURES

Graded beds *Lava pillows*
Direction of tops of beds and basis for determination

LINEAR FEATURES

Bearing and plunge of lineation
Defined by parallel rock fragments or by combination of chlorite or mica rods or both. May be combined with planar features

Bearing and plunge of minor fold axes

SURFACE OPENINGS AND EXPLORATION

Gold mine or large opencut
Additional mine names in southwest part of quadrangle can be found in Eric and others (1955, pl. 3)

Hydraulic mine
Approximate positions in northwest part of quadrangle indicated by mapped tailings, Qt

Small shaft, prospect pit, or opencut for gold

ls
Limestone quarry

Cu
Other mine or prospect
Cu, *copper,* Cr, *chromium,* Mn, *manganese,* a, *asbestos,* tc, *talc*

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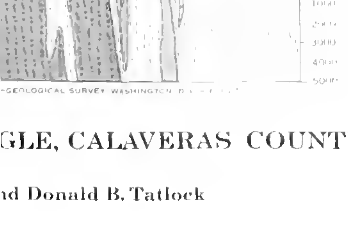

GEOLOGICAL SURVEY, WASHINGTON, D. C.

LITHOLOGIC SYMBOLS USED IN CROSS SECTION

Slate and phyllite
Graywacke
Conglomerate
Metachert
Limestone and dolomitic limestone
Volcanic breccia
Tuff
Lava
Schistose metavolcanic rocks
Schistose metasedimentary rocks

GLE, CALAVERAS COUNTY, CALIFORNIA

nd Donald B. Tatlock

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